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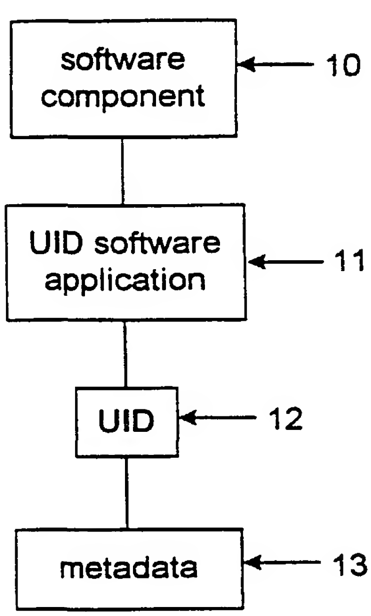

(57) Abstract: Methods and apparatus are provided for generating a unique identifier (12) for a software component (10). The unique identifier (12) is generated using a source-based, secure hash encoding. The source-based, secure hash encoding is applied to a canonical source code format of the software component. The unique identifier (12) is inserted into a meta-data structure (13) associated with the software component.

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METHODS AND APPARATUS FOR GENERATING UNIQUE IDENTIFIERS FOR SOFTWARE COMPONENTS

Field Of The Invention

The present invention relates generally to methods and apparatus for generating unique identifiers for software components. More specifically, the present invention provides methods and apparatus for generating unique identifiers for software components using a source-based, secure hash.

Background Of The Invention

Software systems have become increasingly more powerful and sophisticated due to the development of component-based technology. Component-based software systems are composed of a plurality of independently deployable units of software called *components*. Components generally contain software routines or objects that perform various functions and may be used alone or in combination with other components. Components may also have other types of content, for example, a component may contain an interface definition, a document or a portion of a document, data, digital media, or any other type of independently deployable content that may be used alone or in combination to build applications or content for use on a computer. A component typically encapsulates

a collection of related data or functionality, and may comprise one or more files.

In component-based software systems, it is often desirable or necessary to associate a *unique identifier*, or *UID*, with each component for locating, registering, licensing, and communicating with or between components. A unique identifier serves as a unique label to designate the software component in much the same way a license plate identifies a car, a street address identifies a building, and a ISBN number identifies a book. In all these cases, the identifier is simply a string of characters that follows a format designed to facilitate the interpretation of the information the identifier is conveying. Examples of such identifiers are the 9-digit ZIP code used by the U.S. Postal Service to specify a geographical region and the 10-digit ISBN number used to identify published titles. Both identifiers are unique, compact, and easily parseable.

Preferably, unique identifiers for software components have many of the same properties. Identifiers should be *unique* with respect to the semantics of the software component and within the domain in which they are to be used. Given the set of all existing software components in a domain, no two should have the same identifier unless the components are semantically identical. In distributed software applications, for example, intended to be run on multiple machines over a network, the domain may encompass all the machines that are attached to the network. Given the size and connectivity of today's Internet, along with its projected future growth, the domain over which such unique identifiers may be used could encompass a significant proportion of all of the

computers in the world. Guaranteeing the uniqueness of an identifier for a software component would significantly facilitate the design of mechanisms for locating and referencing the component among many other components in a distributed network.

Identifiers should also be *compact*, that is, they should be relatively small with respect to the software components with which they are associated. Compactness allows components to be referenced quickly and efficiently, and limits the space required to store the UIDs to a manageable amount. The UIDs should be as small as possible while still satisfying the uniqueness requirement.

It is also desirable that unique identifiers be *secure*. Unique identifiers are secure when it is computationally infeasible to reproduce a software component corresponding to a given UID or to create two different components that produce the same identifier. Secure UIDs may also be used for authenticating components to verify their origin and to verify that the components have not been modified by intruders. In this case, both the UID and the source code of the component being authenticated need to be available.

Finally, UIDs for software components should be designed to be *immutable*. An UID must be a constant value that does not change as long as the software component remains the same. This guarantees that communication between components is not interrupted by a change in UIDs, and avoids broadcasting UID changes to all dependent software components. If the software component itself changes significantly, the UID should then change accordingly to reflect the different functionality of the component.

There are several known mechanisms for

generating unique identifiers for software components. The simplest approach assigns a randomly generated UID to a software component and inserts the UID directly into the source code of the software component. The UID may be generated independently of the software component, or it may contain a direct reference to the component, such as using a timestamp that denotes the time the component was created or using the name of the software component itself.

Another approach involves obtaining a unique number from a centralized location in a distributed network and using the unique number to generate the UID. The unique number may form part of the UID or it may consist of the entire UID. Unique numbers need to be retrieved from the centralized location whenever an UID assignment to a software component is desired. The retrieval process may be automatic or manual, which would involve requesting a number from a human administrator. Such an approach is very expensive due to the often required retrievals from the centralized location and the fact that this service may not always be available, causing the system to generate UIDs to fail. This was the approach used by the Cronus distributed programming environment.

A UID may also be generated by combining a timestamp with a local unique value, such as the IP address or other network address of the host on which the software component is being built. This approach is used in the Component Object Model (COM) specification, promulgated by Microsoft Corporation of Redmond, WA, to assign identifiers to software components. If there is no IP address or network address in a given environment, a random number is used in its place.

However, basing a UID on the location of a software component may not be desirable. Using the IP address combined with a timestap to form a UID reduces the effective size of the UID, e.g., the number of bits devoted to the UID, increasing the probability of duplicating UIDs and decreasing the security of the UID. This is due to the fact that, in general, only a small fraction of the hosts in the network will need to generate a UID and only a small fraction of the space devoted to timestamps will be used.

Unique identifiers are usually generated by a separate program and placed directly in the source code of software components. However, placing UIDs into the source code of software components does not guarantee the uniqueness of UIDs. Since software developers often reuse code, it is a real concern that defining UIDs in the source code may cause developers to inadvertently reuse UIDs as well. This may occur when an identifier is accidentally copied between the source code of two components or when a developer inadvertently defines a UID that has already been defined in another component implemented by another developer.

An alternative approach to generating UIDs has been proposed in the Java™ object serialization specification by Sun Microsystems of Palo Alto, CA. The UID is used as a version number for a given class to disambiguate one version of the class from another. Identifying the class requires the class name, which is recommended to be unique by the Java™ specification, and the UID to specify the class version. The UIDs are declared as static variables in the source code of a streamable class and are computed at compile time as a 64-bit *hash* of the class name, interface class name,

methods, and fields. Since the UIDs are used as version numbers for a class, the domain over which they operate is relatively small.

A hash value consists of a bit field generated by a *hashing algorithm* to produce a compact representation of an input message. The Java™ object serialization specification adopts the *Secure Hash Standard SHA-1* as the hashing algorithm used to generate UIDs for a streamable class. The UIDs can be declared in the source code of the streamable class or automatically generated by the Java™ runtime system and stored in memory during execution.

The approaches adopted by the COM architecture and by the Java™ object serialization specification to generate UIDs cannot, however, guarantee that a UID is indeed unique. Because there is not an inherent relationship between the identifier and the underlying source code, it is possible for a software component to change significantly without requiring a change to its identifier as well. In the case of Java™, for example, two software components can contain the same class name, interface class name, methods, and fields and have the same UIDs even though the functions of the two components are significantly different. This becomes a concern when a software component communicates with other components and expects the other components to provide a specific functionality associated with their UIDs. If significant source code changes are made to a software component that causes its functionality to be considerably different and its UID is not changed to reflect the new functionality, it could lead to an older piece of software using a newer version of a software component with which it is not semantically

compatible, or vice-versa.

Additionally, the UIDs used in the Java™ object serialization specification are restricted to identifying the version number of streamable classes. Large software systems may require using a UID in many other contexts, such as locating the software component, negotiating licensing information between components, and easily sharing components in a software system implemented using multiple programming languages. It would be desirable to store the UID together with a variety of descriptive information about the software component so the UID of a software component can be automatically extracted together with bibliographical data, version number, licensing, and other descriptive information.

In view of the drawbacks associated with previously-known methods and apparatus for generating a unique identifier for a software component, it would be desirable to provide methods and apparatus suitable for generating a unique identifier for a software component that overcome these drawbacks.

It would further be desirable to provide methods and apparatus for generating an identifier for a software component that reflects the functionality of the software component.

It would still further be desirable to provide methods and apparatus for generating an identifier for a software component that is unique, compact, immutable, and secure.

It would also be desirable to provide methods and apparatus for automatically generating a unique identifier for a software component and inserting the unique identifier in a *meta-data* structure associated with the software component.

Summary Of The Invention

In view of the foregoing, it is an object of the present invention to provide methods and apparatus suitable for generating a unique identifier for a software component that overcome drawbacks associated with previously-known methods and apparatus.

It is another object of the present invention to provide methods and apparatus for generating an identifier for a software component that is based on the functionality of the software component.

It is a further object of the present invention to provide methods and apparatus for generating an identifier for a software component that is unique, compact, immutable, and secure.

It is also an object of the present invention to provide methods and apparatus for automatically generating a unique identifier for a software component and inserting the unique identifier in a *meta-data* structure associated with the software component.

These and other objects of the present invention are accomplished by providing methods and apparatus for generating a unique identifier for a software component using a secure hash encoding of the source code implementation of the software component. The unique identifier is inserted in a meta-data structure associated with the software component.

In a preferred embodiment, the methods of the present invention for automatically generating a unique identifier for a software component involves three major steps: (1) putting the source code text of the software component into a canonical form; (2) computing a hash encoding based on the canonical form of the source code text to form the unique identifier; and

(3)associating the unique identifier with the software component.

More specifically, the present invention uses a cryptographically secure hashing algorithm as the basis for generating a unique identifier for a software component. The unique identifier is computed by selecting the portions of the source code text that are important to the implementation of the software component. The selected source code text is encoded into a sequence of bits using a standard character encoding algorithm. A cryptographically secure hashing algorithm is applied to the sequence of bits to generate a unique, compact, immutable, and secure hash value that is used as the unique identifier. Since the cost of the secure hashing algorithm is proportional to the number of input bits, the character encoding algorithm should be chosen to produce the most compact encoding for the expected source code. The unique identifier is then associated with the software component, for example, by inserting it into a meta-data structure. Preferably, the unique identifier is generated automatically by special purpose routines that are executed when compiled versions of the software component are created, and embedded in the generated object code. Having the unique identifier be generated automatically at compile time avoids having to read the source code twice, one to compile it, and one to generate the UID. Further, embedding the UID in the object code of the software component ensures that the UID is associated with the most up-to-date version of the component.

An important advantage of the present invention inheres in the fact that the unique identifier is computed using only the portions of the

source code text that are important to the implementation of the software component. This ensures that insignificant changes in the source code of the software component do not produce a different unique identifier for the component. Only changes with respect to the component's functionality would lead to a different unique identifier. This reduces the possibility of assigning the same identifier to two software components that have distinct functions.

Another technical advantage of the present invention inheres in the fact that the unique identifier of a software component is automatically generated when the source code is being compiled and thus requires no human intervention and presents no possibility of human error.

In the preferred embodiment of the invention, the UID is inserted into a meta-data structure associated with the compiled software component. This enables unique identifiers of software components to be easily accessible for several purposes, including location, registration, and licensing of components.

Other technical advantages of the present invention will become apparent to one of ordinary skill in the art in view of the drawings and detailed description of the embodiments of the invention.

Brief Description Of The Drawings

The above and other objects of the present invention will be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which like reference characters refer to like parts throughout, and in which:

FIG. 1 is a schematic view of a preferred

embodiment of a software system for generating a unique identifier for a software component;

FIG. 2 is a schematic view of the structure of a meta-data associated with a software component built in accordance with the principles of the present invention;

FIG. 3 is a simplified block diagram of an illustrative software application for automatically generating a unique identifier for a software component using a source-based, secure hash in accordance with the principles of the present invention;

FIG. 4 is a flow chart for putting the source code text of the software component into a canonical form;

FIGs. 5A and 5B are schematic views of two embodiments of a process for generating a unique identifier for a software component;

FIG. 6 is a schematic view of a computer system suitable for use with the present invention; and

FIG. 7 is an illustrative computing environment on which the methods and apparatus of the present invention may be used.

Detailed Description Of The Invention

Referring to FIG. 1, a preferred embodiment of a system for generating a unique identifier for a software component is described. Software component 10 is an independently deployable unit of software that may be used, e.g., "imported", by other software. Components generally contain software routines or objects that perform various functions and may be used alone or in combination with other components. Components may also have other types of content, for example, a component may contain an interface

definition, a document or a portion of a document, data, digital media, or any other type of independently deployable content that may be used alone or in combination to build applications or content for use on a computer. Components preferably contain well-defined *interfaces*, so that one or more components can be interconnected to build software applications, without requiring detailed knowledge of the inner workings of the components. A component typically encapsulates a collection of related data and functionality, and may comprise one or more files. For example, a component may consist of a single file that implements a bounding box for text, a component may consist of multiple files that implement a spell checker that uses the component for building a bounding box, or a component may consist of an entire word processor, using multiple components that implement diverse functions such as generating bounding boxes or checking the spelling.

The source code text of software component 10 is used as an input to UID software application 11, which comprises a set of special purpose routines for automatically generating a UID for a software component. UID software application 11 may be built as a separate custom-built software application or it may be integrated into programming language compilers or a development environment. In a preferred embodiment of the present invention, the UID software application is part of the compiler, since the compiler must read the source code to perform its functions.

UID software application 11 generates as output unique identifier (UID) 12. As used herein, a UID is a series of bits or a bit field that serves as a label associated with a software component. A UID can be used for identifying, locating, registering,

licensing, and communicating with components. In a preferred embodiment of the invention, UID software application 11 ensures that UID 12 is unique within the domain it is used, compact and relatively small with respect to software component 10, immutable, and secure. Upon being generated, UID 12 is inserted into meta-data structure 13 associated with software component 10.

Referring now to FIG. 2, the structure of meta-data 13 according to the principles of the present invention is described. Meta-data 13 includes a variety of information about software component 10. This information should minimally include the name of software component 10 and UID 12. Alternatively, UID 12 may be used as the only reference mechanism for software component 10, which in this case, would not necessarily have a name. Meta-data 13 may also include a variety of other information, as described in detail hereinbelow. Parts of meta-data 13 may be specified by a programmer at the time software component 10 is written, while other parts must be computed, and added to meta-data 13. UID 12 is an example of a part of meta-data 13 that is computed by UID software application 11. Similarly, meta-data such as the time at which a component was released would typically be computed and added to meta-data 13 by a release tool or by a development environment.

As shown in FIG. 2, meta-data 13 comprises a series of key-value pairs. Keys 14a - 14d identify particular items of meta-data by name. For example, unique identifier 12 may use "id" as a key, while a meta-data item containing the name of the author of a component may use "author" as a key. Values 15a - 15d are meta-data values associated with keys 14a - 14d.

These values contain information pertaining to the particular component with which the meta-data is associated.

In a preferred embodiment, meta-data 13 may include the items listed in table 1. It will be understood that the meta-data associated with a component may vary, and that some systems will use a different set of meta-data than that shown in FIG. 2 or table 1. Additionally, it will be understood that some of the meta-data items listed in table 1, such as the name of the component, may be stored separately from other key-value pairs, due to their presence in almost all components, or the frequency with which they are accessed. Certain of the meta-data items listed in Table 1, such as "author", and "name", will be given values by the programmer or content developer, while others, such as "compilation-time" and "id" will be generated by a compiler or development environment.

TABLE 1 - Common Meta-data Items

Meta-data Key	**Description**
name	The name of the component.
version	The version number of the component.
id	Unique ID for the component.
author	The author(s) of the component.
compilation-time	The time at which the instance of the component was compiled.
component-type	The type (e.g., "package" or "document") of the component.
copyright	A copyright notice for the component.

files	A list of the files included in the component.
frozen?	Indicates whether the component is "frozen". If the component is "frozen", any attempt to change its meta-data will result in an error.
jit-compiled?	Indicates whether the component instance was JIT compiled.
source-url-name	The URL of the file from which the component was compiled.
system-versions	The versions of the system on which the component may be used.
transitive-id	A unique component ID that incorporates the IDs of all components on which the component depends.

Referring to FIG. 3, a block diagram of UID software application 11 is described.

UID software application 11 consists of three stages. First, at stage 16, a canonical source code format is generated by selecting only the portions of the source code text that are important to the implementation of the software component. Second, at stage 17, the canonical form of the source code text is encoded into a sequence of bits using a character encoding algorithm. Lastly, at stage 18, a hashing algorithm is applied to the sequence of bits to generate a hash value that is used as the UID associated with a software component.

Referring now to FIG. 4, a flow chart of stage 16 for generating a canonical source code format used to represent the software component is described.

The canonical source code format is generated to avoid creating a different identifier every time an insignificant change is made on the source code that does not affect the semantics or implementation of the software component. A source code change is insignificant when it does not affect the semantics or implementation of the software component. The canonical source code format removes all the insignificant portions of the source code text. The insignificant portions of source code text depend on the programming language used to write the source code text. Examples of insignificant portions of source code text include certain whitespaces, certain comments, and other characters.

At step 20, any character that is not significant to the semantics or implementation of the software component is discarded. Unless it would alter the functionality of the software component, any remaining whitespaces are converted to a canonical whitespace character, typically the space character. Significant whitespaces are those required by the programming language specification or those that have an effect on the output of the software component. Examples of significant whitespaces include spaces between the type definition of a variable and its name, and spaces included in strings that are part of the output of the software component. Insignificant whitespaces include spaces used for indentation of the source code and spaces in the source code comments.

For example, consider the following fragment of code implemented using the C programming language:

```
int
main()
{
```

```
        printf("Hello     World!");
        return 0;
    }
```

After removing insignificant characters at step 20, the code above is reduced to:

```
    int main(){printf("Hello     World!");return 0;}
```

The above example shows that the extra spaces in the string "Hello   World!" are not discarded because this would affect the output of the software component.

If the source code text is not case sensitive (step 21), then the selected source code text is converted at step 22 to a single case, either lower case or upper case. At step 23, all comments included by a developer that are not significant to the output and functionality of the software component are discarded. Special documentation comments that are supported in certain programming languages are not discarded, since they form an important part of the software component.

At step 24, a decision is made on whether the source code used to represent the software component is selected solely from portions that denote the external interface of the software component. The external interface of a software component is used to specify how the software component interacts or communicates with other software components. The software component may be represented solely by its external interface when, for example, the software component is implemented by multiple programming languages. In case the source code used to represent the software component is to denote only the external interface, then those parts of the source code that do not contribute to this external interface are omitted at

step 25.

Referring back to FIG. 3, upon generating the canonical source code format at stage 16, stage 17 encodes the canonical source code format into a sequence of bits. The sequence of bits is generated using a standard character encoding algorithm, such as ASCII, ISO Latin-1, UCS-2, or UTF-8, or a custom-built character encoding algorithm. The character encoding algorithm selected should support all the characters that occur in the programming language used to write the source code text and produce the most compact sequence of bits for the canonical source code format. For example, the portion "int main" of the canonical source code format described above

```
int main(){printf("Hello    World!");return 0;}
```

may be encoded into the following sequence of bits using the 7-bit ASCII character encoding:

```
1101001 1101110 1110100 0100000 1101101 1100001
1101001 1101110
```

Each character of the "int main" string is converted into a 7-bit field. The UTF-8 algorithm may be a good choice when the underlying source code accepts the Unicode character set but it is expected that most characters in the source code are in the ASCII set.

The sequence of bits is then used at stage 18 by a *hashing algorithm* to generate a hash value that forms the UID for the software component. A hash value consists of a bit field that is generated by a hashing algorithm to produce a compact representation of an input message. For example, the character encoding described above for the string "int main"

```
1101001 1101110 1110100 0100000 1101101 1100001
1101001 1101110
```

may be reduced to the following hash value by using a

simple hashing algorithm that consists of combining all of the bytes of the string using bitwise exclusive-or:

1011000

Because the hash values are in general much smaller than the original message, there can be more than one message that will produce the same hash value; this is known as a *hash collision.* Such collisions are unacceptable if the hash encoding is intended to be used as a unique identifier. Two messages should have the same hash value if and only if the messages are identical. The hash encoding algorithm should therefore be chosen to provide an extremely low probability of collisions over the set of expected messages to be encoded. For practical implementation purposes, the hashing algorithm should also be chosen such that the hash value is easily computable on a message of arbitrary length.

One group of hashing algorithms that fits this description is the set of cryptographically secure hashing algorithms, which have been designed for use in data authentication and encryption. Such algorithms are designed to produce a secure digest of a given message that can be used to authenticate the contents of the message. Examples of such algorithms include MD-5, RIPEMD-128, RIPEMD-160, and the *Secure Hash Standard SHA-1* adopted by all Federal departments and agencies for the protection of unclassified information. In a preferred embodiment of the invention, the SHA-1 algorithm is used to generate the UID for a software component because it generates 160-bit hash values instead of the 128-bit hash values generated by RIPEMD-128 and MD-5. The main advantage is that the larger number of hash values generated with the 160-bit algorithms than with the 128-bit algorithms

provides a lower probability of collisions. Although RIPEMD-160 also generates 160-bit hash values, the SHA-1 algorithm is more widely used in the U.S. and is recommended by the U.S. government.

Referring now to FIGS. 5A and 5B, two illustrative embodiments of a process for generating a unique identifier for a multi-file software component are described. Component source codes 28 and 29 contain the source code of different files of software component 27. The files may represent parts of source code text from component 27 such as header files or library files, or they may represent individual components or interfaces that are used in combination to form component 27. Component source codes 28 and 29 may be written in a variety of languages, including programming languages such as C and Java™, markup languages such as HTML, hybrid content/programming languages such as CURL (described in commonly owned, copending, U.S. patent application No. ___________ (CURL-002)), and interface definition languages (IDLs) such as CORBA IDL. In multi-language environments, in particular, in environments involving languages that have closely related syntax, it may be necessary to encode the name and version of the language in the UID to distinguish between software components with identical source code that behave differently because the components were compiled using different language rules.

With respect to FIG. 5A, software component source codes 28 and 29 are combined by concatenation routine 30 to generate a single piece of source code that is used by UID software application 11 to form UID 31. The order in which the components are concatenated may be the alphabetical order of software component

source codes 28 and 29, the order in which software component source codes 28 and 29 are compiled, the order according to the number of lines in software component source codes 28 and 29, or an order established by a sorting algorithm that sorts software component source codes 28 and 29 according to their contents. Any method to determine the order should be used consistently, so that the same set of source code files generates the same UID regardless of the order in which the files are processed.

UID software application 11 generates UID 31 based on the single piece of source code formed at 30 by concatenating software component source codes 28 and 29. UID 31 is then inserted in a meta-data structure 32 associated with software component 27.

With respect to FIG. 5B, UID software application 11 is applied individually on software component source codes 28 and 29 to generate a *file identifier* UID for each of software component source codes 28 and 29. A file identifier is a UID that identifies a source code file of a software component. UID 33 is generated for software component source code 28 and UID 34 is generated for software component source code 29. UIDs 33 and 34 are combined at 35 to form UID 36. It is important to combine the UIDs using operations that generate a UID that is unique, compact, immutable, and secure. One requirement is that the domain of the operations not be significantly smaller than the domain of the unique identifiers; that is, given an arbitrary identifier *I*, the set of identifiers produced by applying the operations to I and every possible identifier is the set of all possible identifiers, or very close to it.

One set of operations that fits this

description are the operations which form an algebraic group over the set of possible identifiers. It is assumed that the set of possible identifiers is the same as the set of integers less than a particular power of two, which is referred to as *n*. Three operations may be used to combine the UIDs: exclusive-or, 2's complement addition, and addition modulo 2^n. The exclusive-or and 2's complement addition operations are the fastest, and should preferably be used in practice. The exclusive-or operation should be avoided in case there is a significant probability of having to combine UIDs that are identical. This occurs for example, when there are identical pieces of source code text. In this case, applying the exclusive-or operation to identical UIDs would produce a zero-value UID. An example includes a software component that contains backups of multiple pieces of source code text that are identical to the original pieces of source code.

If software component source codes 28 and 29 contain the source code of individual components or interfaces that are used in combination to form software component 27, then the UID 36 is called a *transitive UID*. The transitive ID is a unique component ID that incorporates the IDs of all components on which component 27 depends.

It will be understood by one skilled in the art that other combination methods could also be used in accordance with the principles of the present invention, and that any of these techniques may be used alone, or in combination.

Referring now to FIG. 6, a computer capable of generating a UID for a software component in accordance with the principles of the present invention

is described. Computer system 38 includes at least processor 39, for processing information according to programmed instructions for generating a UID for a software component, memory 40, for storing information and instructions for processor 39, and storage system 41, such as a magnetic or optical disk system, for storing large amounts of information and instructions on a relatively long-term basis. Processor 39, memory 40, and storage system 41 are coupled to bus 42, which preferably provides a high-speed means for devices connected to bus 42 to communicate with each other.

It will be apparent to one of ordinary skill in the art that computer system 38 is illustrative, and that alternative systems and architectures may be used with the present invention. It will further be understood that many other devices, such as a display system (not shown), a network interface (not shown), and a variety of other input and output devices (not shown) may be included in computer system 38.

Referring to FIG. 7, an example of a computing environment in which the methods and apparatus of the present invention may be used is described. Computers 43, 44, and 45, and server 46 are connected to local area network (LAN) 47. Each of computers 43, 44, and 45 may execute a variety of software, all or part of which may be stored locally on computers 43, 44, or 45, or may be stored on server 46, and accessed over LAN 47.

LAN 47 is connected to a wide area network (WAN) 48, such as the Internet, through gateway 49, which may be a dedicated device, or may be a computer or server, similar to computers 43, 44, and 45, or server 46. By sending communications across WAN 48, any of the devices connected to LAN 47 may communicate

with remote server 50, or with other devices or networks connected to WAN 48. Computers 43, 44, and 45 may gain access to information and software components on other computers through WAN 48.

It will be understood by one skilled in the art that the above-described environment is for illustration, and that the present invention may be used under a variety of conditions. For example, the methods and apparatus of the present invention could be used on a single stand-alone computer, but would then be unable to access information or software over LAN 47 or WAN 48. Generally, the present invention may be used with any configuration of one or more computers, which may be interconnected on one or more networks.

Although particular embodiments of the present invention have been described above in detail, it will be understood that this description is merely for purposes of illustration. Specific features of the invention are shown in some drawings and not in others, and this is for convenience only and any feature may be combined with another in accordance with the invention. Steps of the described processes may be reordered or combined, and other steps may be included. Further variations will be apparent to one skilled in the art in light of this disclosure and are intended to fall within the scope of the appended claims.

What Is Claimed Is:

1. A method of generating a unique identifier for a software component, the method comprising:

transforming source code text of the software component into a canonical source code format;

encoding the canonical source code format into a sequence of bits;

computing a hash of the sequence of bits to form the unique identifier; and

associating the unique identifier with the software component.

2. The method of claim 1, wherein associating the identifier with the software component comprises inserting the identifier in a meta-data structure.

3. The method of claim 1, wherein the software component comprises a plurality of source code files, and wherein transforming source code text of the software component into a canonical source code format involves concatenating the source code files into a single file.

4. The method of claim 3, wherein concatenating the source code files into a single file comprises ordering the source code files.

5. The method of claim 4, wherein ordering the source code files comprises selecting an order from a group consisting of:

alphabetical order of the name of the source code files;

order according to the number of lines in the source code files;

order in which the source code files are compiled; and

order established by a sorting algorithm that sorts the source code files according to their contents.

6. The method of claim 1, wherein transforming source code text of the software component into a canonical source code format comprises

discarding insignificant characters;

converting remaining whitespaces into a canonical whitespace character if the remaining whitespaces do not have an effect on the compiled component;

determining whether the programming language used to write the source code text is case-insensitive, and if so, converting the respective source code text into a single case; and

discarding insignificant comments.

7. The method of claim 6, further comprising discarding all portions of the source text that do not contribute to an external interface of the software component if the software component is to be identified only by its external interfaces.

8. The method of claim 1, wherein encoding the canonical source code format into a sequence of bits comprises encoding the canonical source code format using a character encoding algorithm.

9. The method of claim 1, wherein computing a hash of the sequence of bits to form the unique identifier comprises applying a cryptographically secure hashing algorithm on the sequence of bits.

10. The method of claim 1, wherein the meta-data structure comprises a variety of descriptive information about the software component, such as bibliographical information, version number of the software component, compilation information, and licensing information.

11. A method of generating a unique identifier for a software component consisting of a plurality of source code files, the method comprising:

generating a unique file identifier for each source code file;

combining the file identifiers to form the unique identifier for the software component; and

inserting the unique identifier into a meta-data structure associated with the software component.

12. The method of claim 11, wherein generating a unique file identifier for a source code file comprises

transforming the source code text of the source code file into a canonical source code format;

encoding the canonical source code format into a sequence of bits;

computing a hash of the sequence of bits to form the file identifier.

13. The method of claim 12, wherein transforming source code text of the source code file into a canonical source code format comprises

discarding insignificant characters;

converting remaining whitespaces into a canonical whitespace character if the remaining whitespaces do not have an effect on the compiled component;

determining whether the programming language used to write the source code text is case-insensitive, and if so, converting the respective source code text into a single case; and

discarding insignificant comments.

14. The method of claim 13, further comprising discarding all portions of the source text that do not contribute to external interfaces of the source code file if the file identifier for the source code file is to denote only the external interfaces of the source code file.

15. The method of claim 12, wherein encoding the canonical source code format into a sequence of bits comprises encoding the canonical source code format using a character encoding algorithm.

16. The method of claim 12, wherein computing a hash of the sequence of bits to form the file identifier comprises applying a cryptographically secure hashing algorithm on the sequence of bits.

17. The method of claim 11, wherein combining the file identifiers to form the unique identifier comprises using a bitwise exclusive-or routine.

18. The method of claim 11, wherein combining the file identifiers to form the unique identifier comprises using an addition modulo 2^n routine, wherein n is the number of bits used to represent the file identifiers.

19. The method of claim 11, wherein combining the file identifiers to form the unique identifier comprises using an addition modulo p routine, wherein p is the largest prime number smaller than 2^n, wherein n is the number of bits used to represent the file identifiers.

20. The method of claim 11, wherein the meta-data structure comprises a variety of descriptive information about the software component, such as bibliographical information, version number of the software component, compilation information, and licensing information.

21. A software component, comprising a unique identifier that represents a secure hash of the significant portions of source code text of the software component, and a meta-data structure in which the unique identifier is stored along with a variety of descriptive information about the software component.

22. The software component of claim 21, wherein a secure hash of the significant portions of source code text of the software component comprises applying a cryptographically secure hashing algorithm to the significant portions of source code text of the software component.

23. The software component of claim 22, wherein the significant portions of source code text of the software component comprise the portions of source code text that are important to the implementation of the software component.

24. The software component of claim 23, wherein the portions of source code text that are important to the implementation of the software component comprise source code text that determines the functionality of the software component and certain source code comments.

25. The software component of claim 21, wherein the meta-data structure comprises a variety of descriptive information about the software component, such as bibliographical information, version number of the software component, compilation information, and licensing information.

26. An apparatus for generating unique identifiers for a software component, the apparatus comprising:

a general purpose computer;

a memory, the memory storing a plurality of routines for execution by the processor, wherein the plurality of routines comprise:

a transformation routine that selects source code text from the software component to generate a canonical source code format;

an encoding routine to encode the canonical source code format into a sequence of bits;

a hash encoding routine to compute a hash value from the sequence of bits to form the unique identifier;

numerical operation routines to combine multiple hash values into a single hash value; and

an embedding routine to insert the unique identifier into a meta-data structure associated with the software component.

27. The apparatus of claim 26, wherein the transformation routine comprises the steps of:

a) discarding insignificant whitespaces and converting any remaining whitespaces into a canonical whitespace character if the remaining whitespaces do not have an effect on the compiled component;

b) determining whether the programming languages used to implement the software components are case-insensitive, and if so, transforming respective source code into a single case; and

c) discarding insignificant comments.

28. The apparatus of claim 27, further comprising discarding all portions of the source code text that do not contribute to external interfaces of the software component if the software component is to be identified only by its external interface.

29. The apparatus of claim 26, wherein the encoding routine comprises applying a character encoding algorithm to the canonical source code format.

30. The apparatus of claim 26, wherein the hash encoding routine comprises generating a hash value using a cryptographically secure hashing algorithm for the sequence of bits.

31. The apparatus of claim 26, wherein numerical operation routines to combine multiple hash values into a single hash value comprises:

a bitwise exclusive-or routine;

a routine that performs addition modulo 2^n, wherein n is the number of bits used to represent the hash values; and

a routine that performs addition modulo p, wherein p is the largest prime number smaller than 2^n.

32. The apparatus of claim 26, wherein the meta-data structure comprises a variety of descriptive information about the software component, such as bibliographical information, version number of the software component, compilation information, and licensing information.

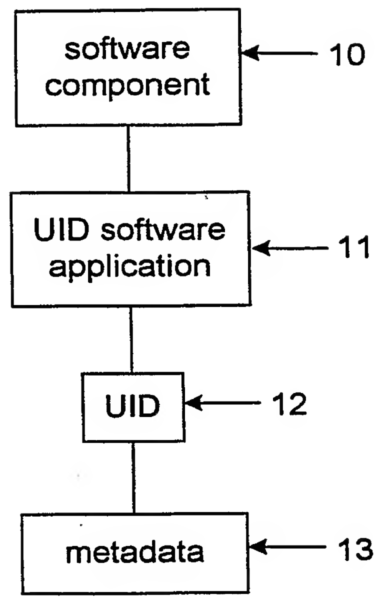
software component
10
UID software application
11
UID
12
metadata
13

FIG. 1

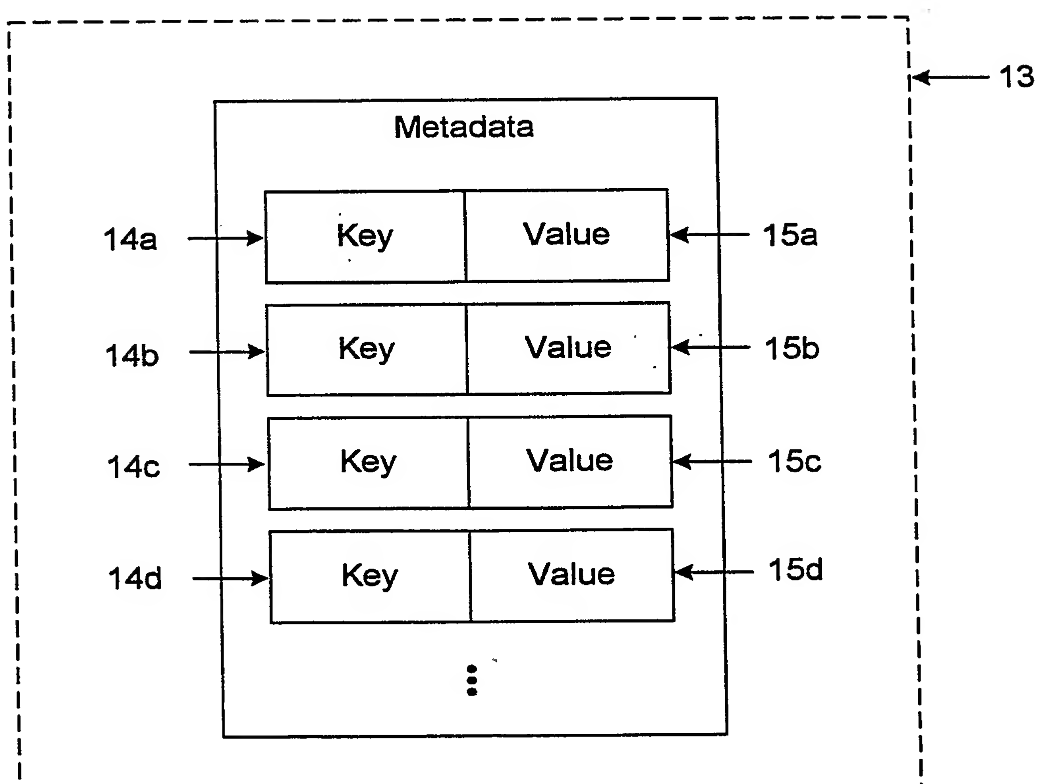
13
Metadata
14a
Key
Value
15a
14b
Key
Value
15b
14c
Key
Value
15c
14d
Key
Value
15d

FIG. 2

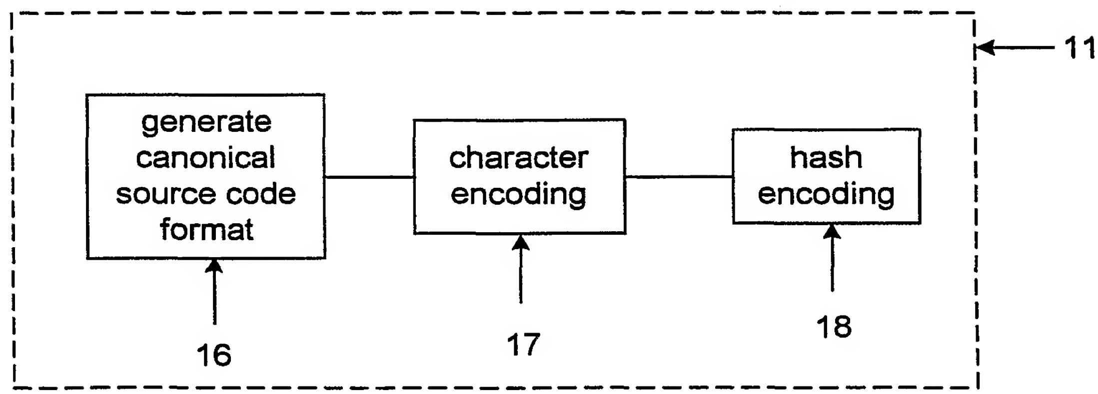
generate canonical source code format
character encoding
hash encoding
11
16
17
18

FIG. 3

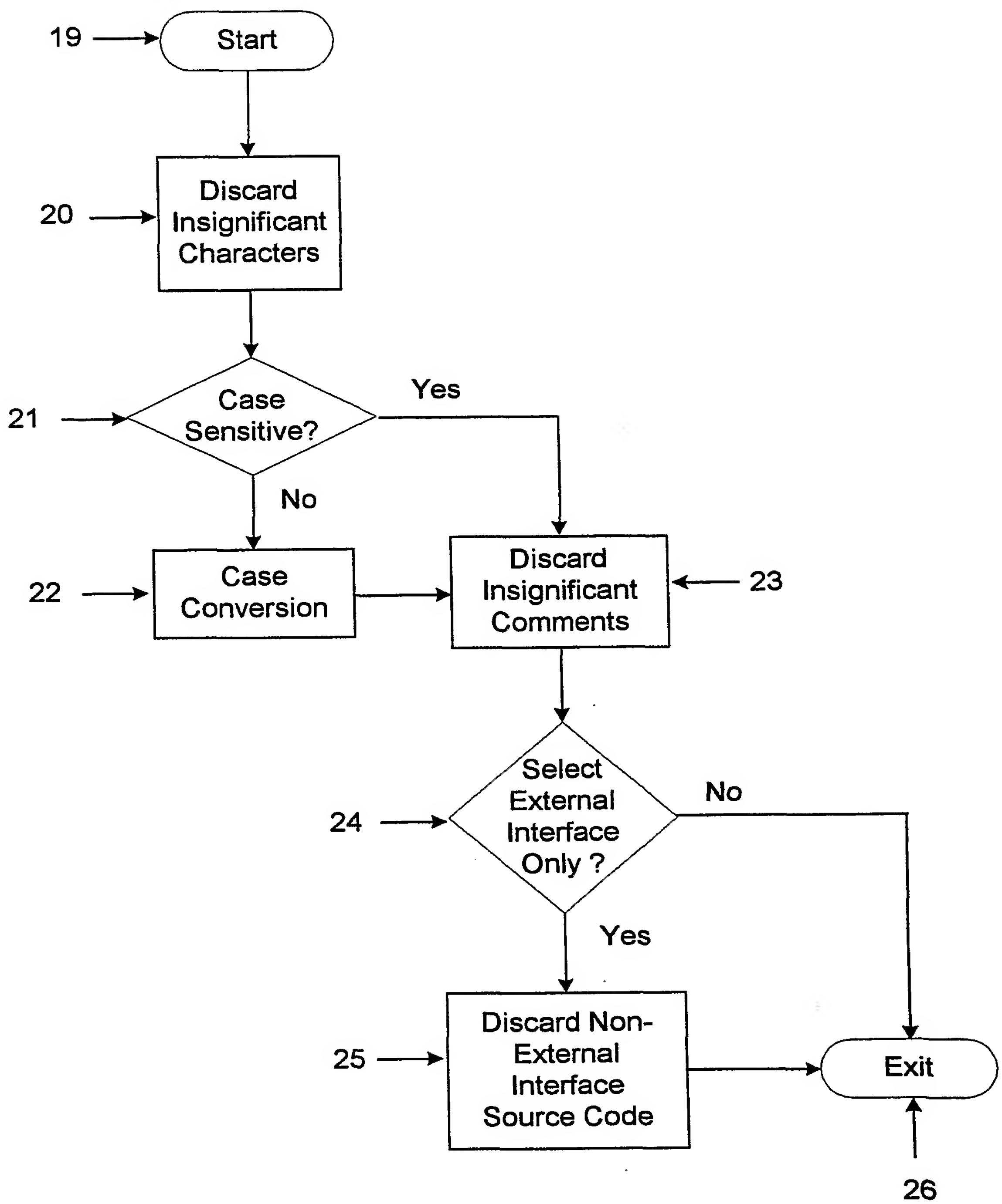
19
Start
20
Discard Insignificant Characters
21
Case Sensitive?
Yes
No
22
Case Conversion
Discard Insignificant Comments
23
24
Select External Interface Only ?
No
Yes
25
Discard Non-External Interface Source Code
Exit
26

FIG. 4

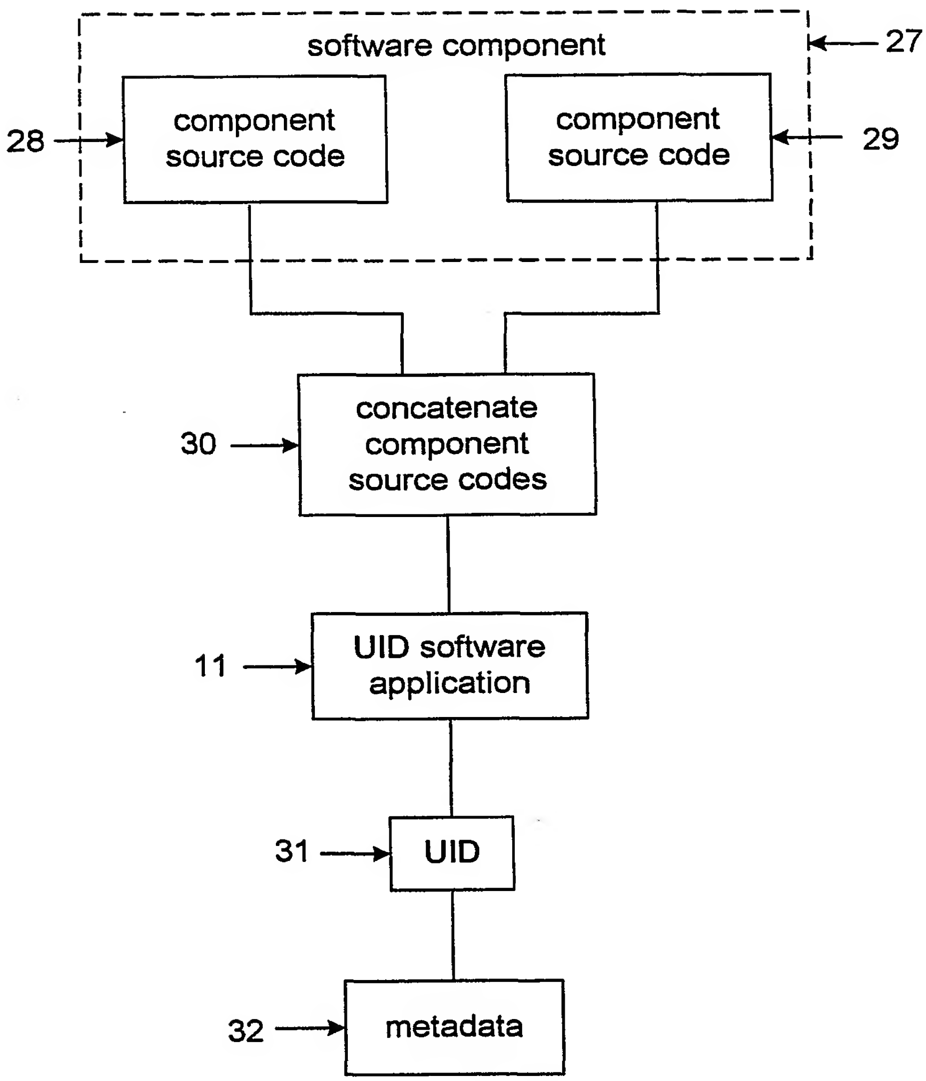
software component
27
28
component source code
component source code
29
30
concatenate component source codes
11
UID software application
31
UID
32
metadata

FIG. 5A

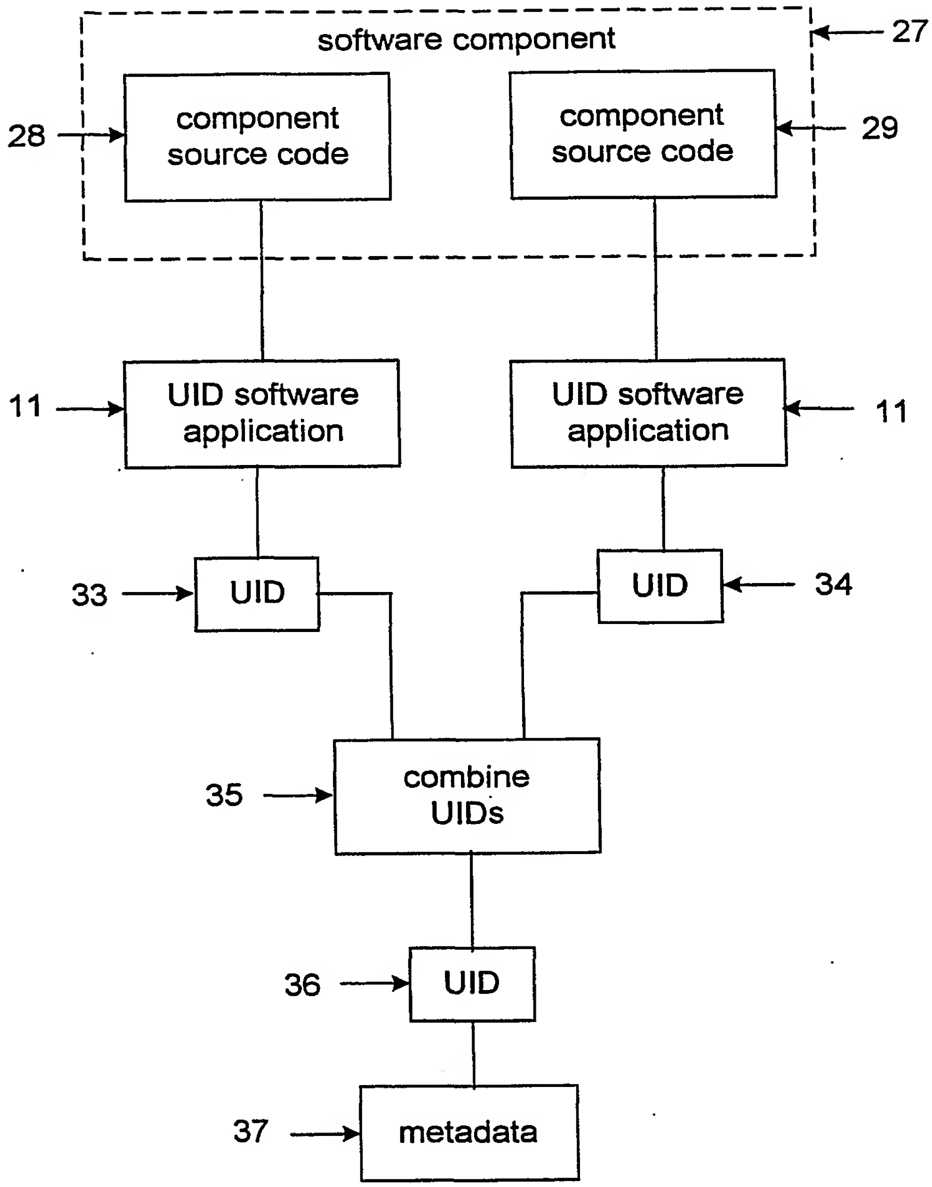
software component
component source code
component source code
27
28
29
UID software application
UID software application
11
11
UID
UID
33
34
combine UIDs
35
UID
36
metadata
37

FIG. 5B

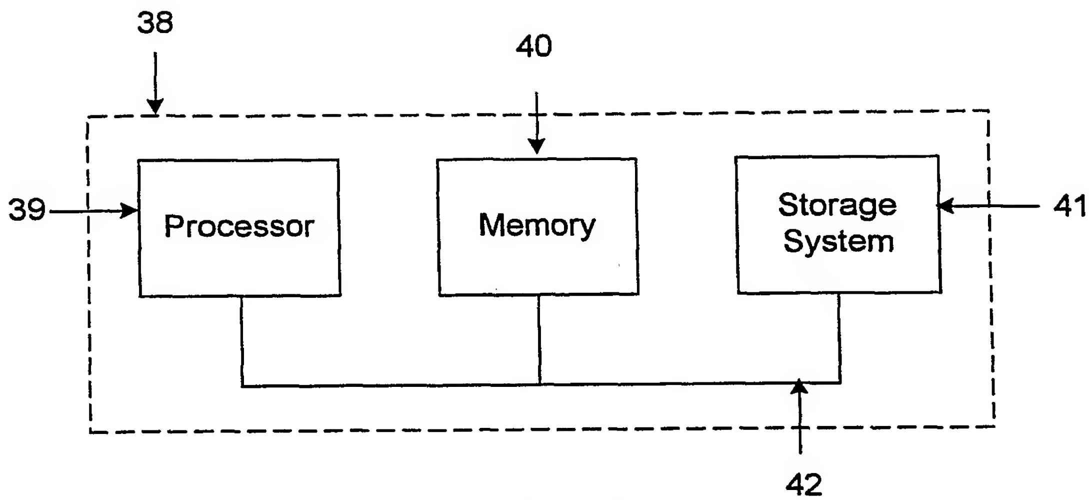
38
40
39
Processor
Memory
Storage System
41
42

FIG. 6

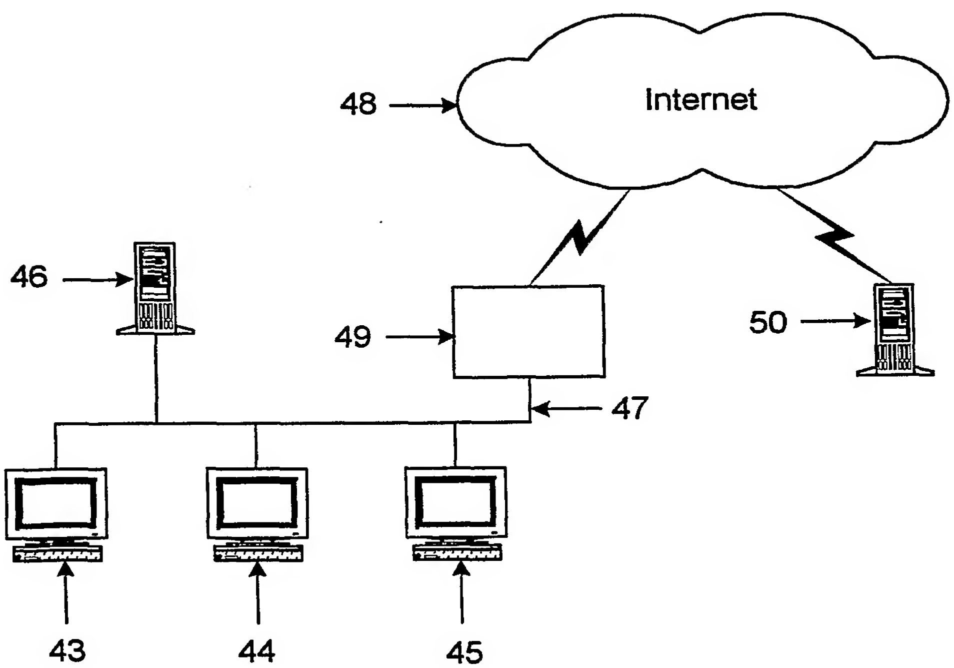
48
Internet
46
49
50
47
43
44
45

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/42341

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G06F 9/44; H04K 1/00
US CL :380/44; 713/167; 717/10, 11
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 380/44; 713/167; 717/10, 11

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WEST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,500,881 A (LEVIN et al) 19 March 1996, col. 3, line 14 to col. 4, line 14; col. 8, line 65 to col. 10, line 44; col. 12, line 57 to col. col. 18, line 19; col. 18, line 29 to col. 55, line 67.	1-32
Y	US 6,098,054 A (MCCOLLOM et al) 01 August 2000, col. 3, line 66 to col. 8, line 28.	1-32
Y,P	US 6,243,468 B1 (PEARCE et al) 05 June 2001, col. 3, line 66 to col. 9, line 14.	1-32

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:
"A"	document defining the general state of the art which is not considered to be of particular relevance
"E"	earlier document published on or after the international filing date
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed
"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search 17 NOVEMBER 2001	Date of mailing of the international search report 17 DEC 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer MATTHEW ~~SMITHERS~~ James R. Matthews Telephone No. (703) 308-9293

Form PCT/ISA/210 (second sheet) (July 1998)★